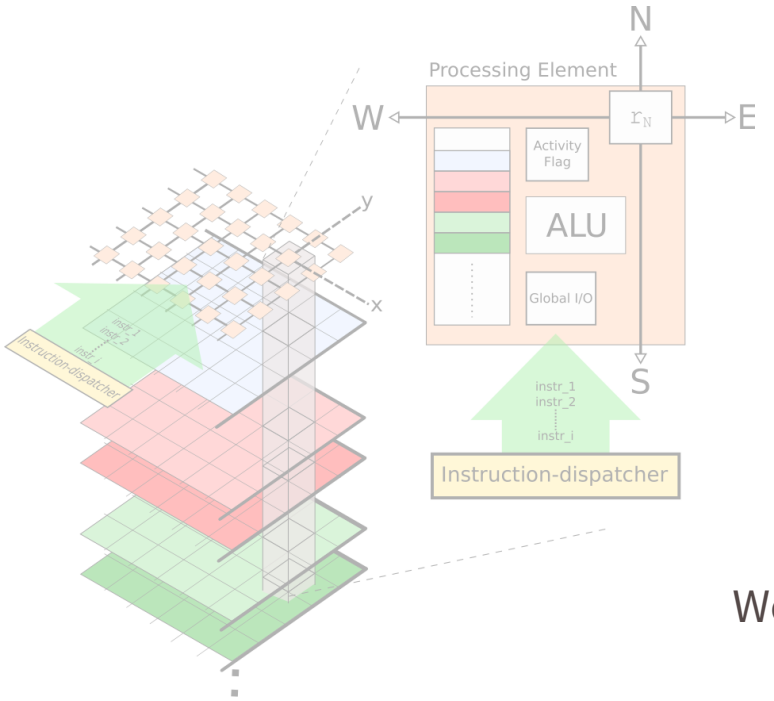
STANFORD COMPUTATIONAL IMAGING LAB

Bringing computation in the focal plane

Sensors with in-pixel processing to enable novel algorithms and systems

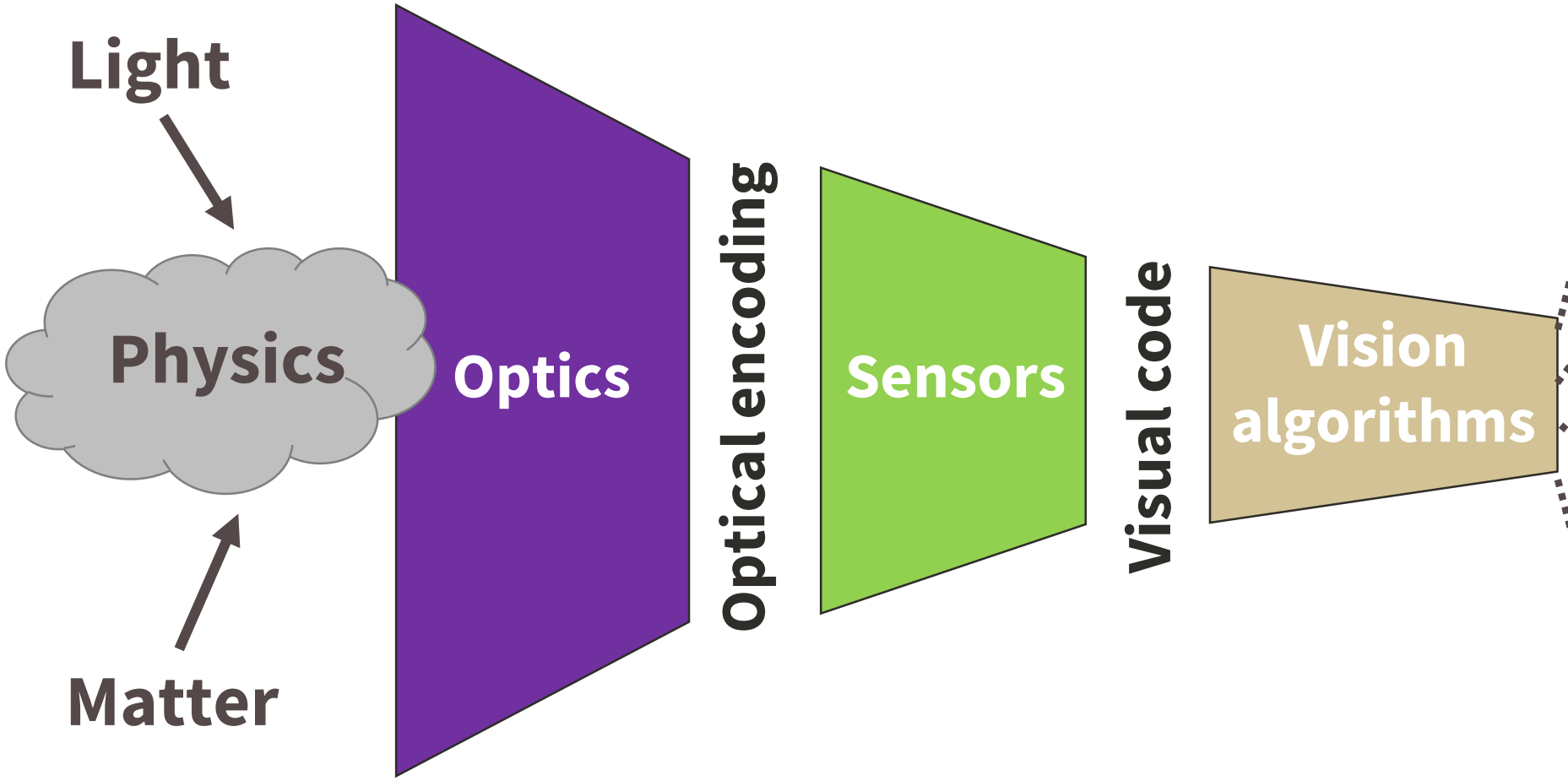


Julien N.P. Martel

jnmartel@stanford.edu

Workshop on Event Based Vision and Smart Cameras
June 17th, CVPR'19

Recovering visual quantities of interest from light



Properties of the scene
- Motion of objects
- Reflectance
- Identity of objects
- Spatial extent of objects

...

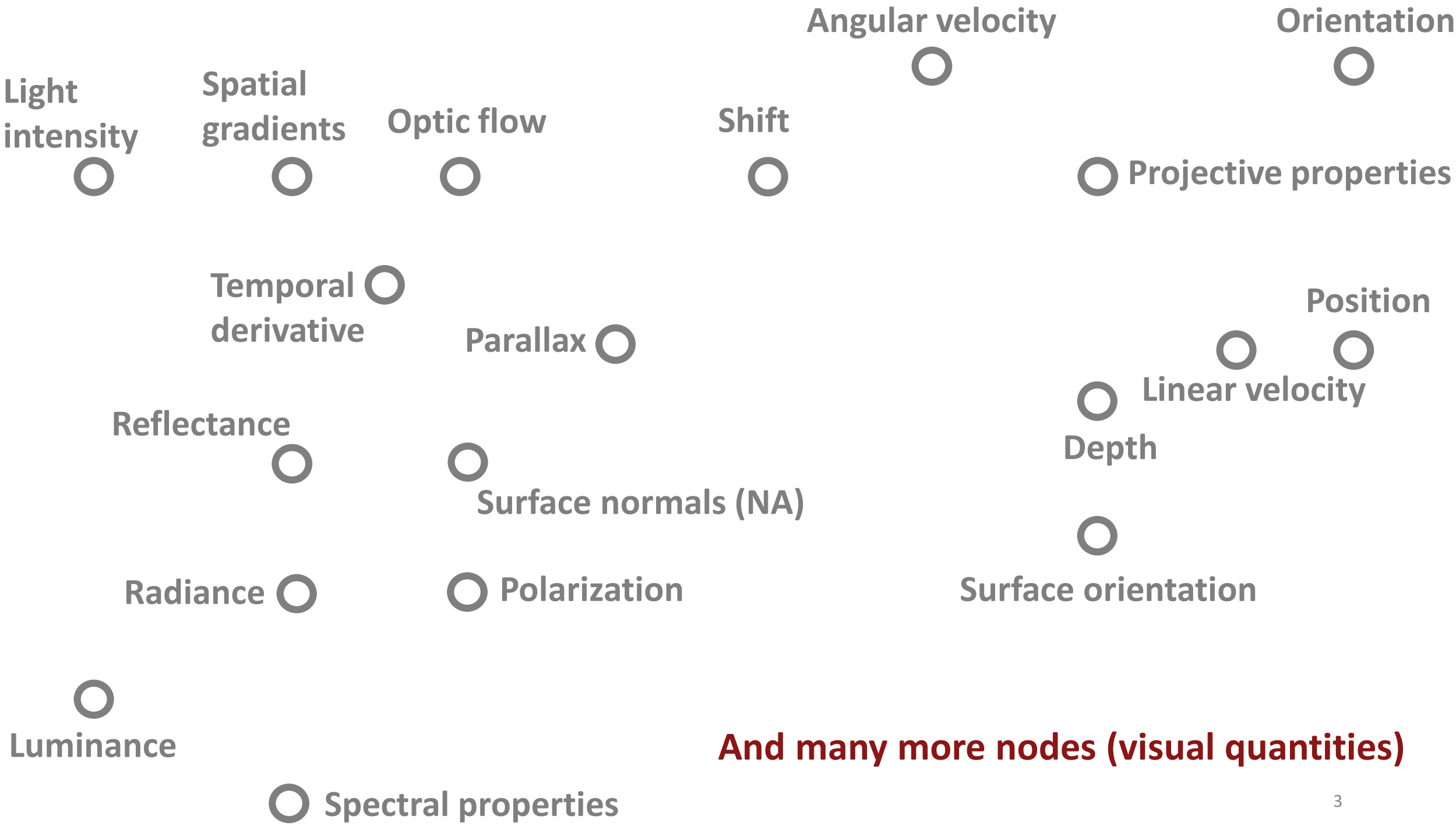
Properties of the observer
- Motion of the observer
- Optical properties

...

Properties of the light sources
- Transmittance
- Polarization
- Position / Orientation

...

and more!


Angular velocity
Orientation
Light intensity
Spatial gradients
Optic flow
Shift
Projective properties
Temporal derivative
Position
Parallax
Linear velocity
Reflectance
Depth
Surface normals (NA)
Radiance
Polarization
Surface orientation
Luminance
Spectral properties
And many more nodes (visual quantities)

Light intensity

Spatial gradi

Optic flow

Angular velocity

Orientation

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Refl

Surface normals (

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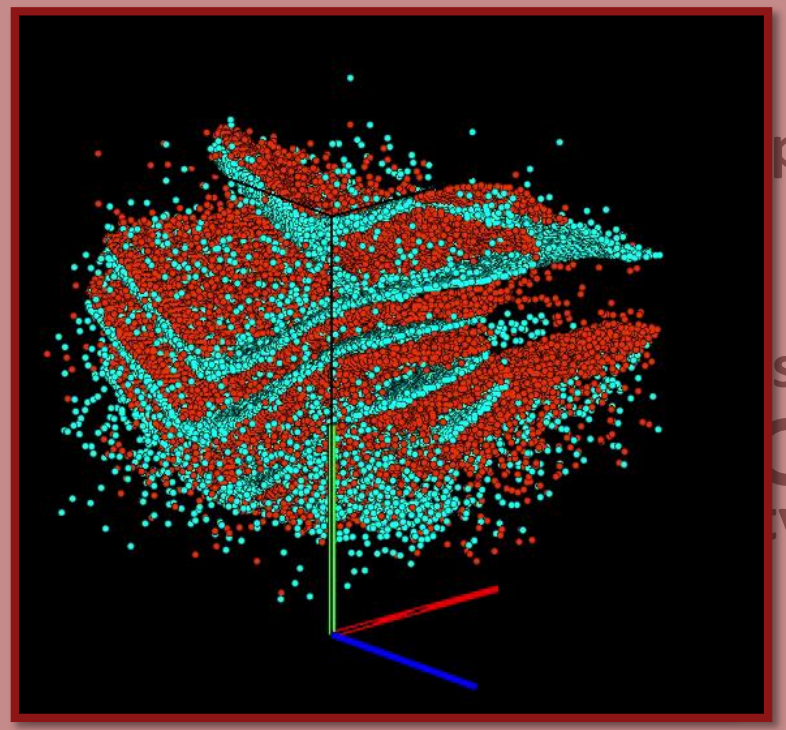

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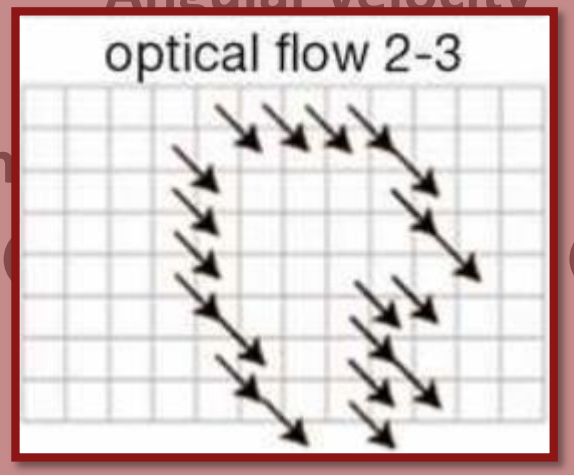

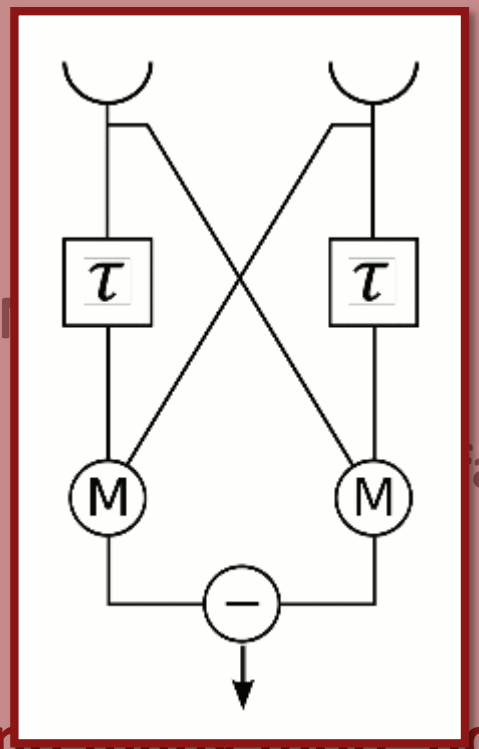

And many more modes (visual quantities)

Angular velocity

Orientation

Light intensity

Spatial gradients

Optic flow

Source: V. Gruev @ UIUC

Projective properties

Position

Parallax

Linear velocity

Depth

Surface normals (NA)

Radiance

Polarization

Surface orientation

Luminance

And many more nodes (visual quantities)

Spectral properties

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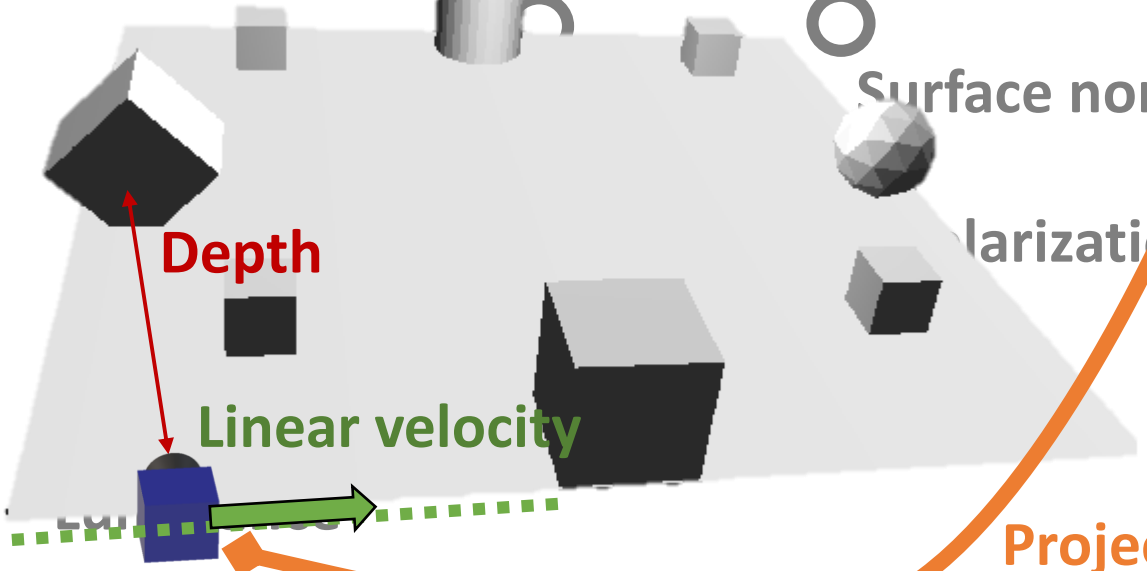
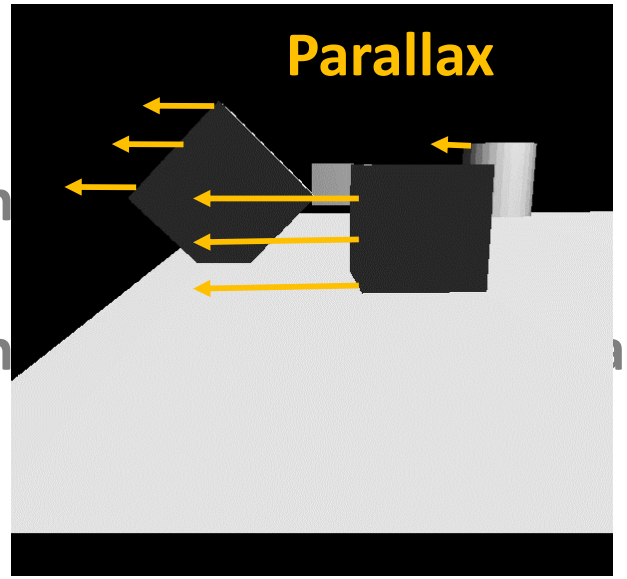
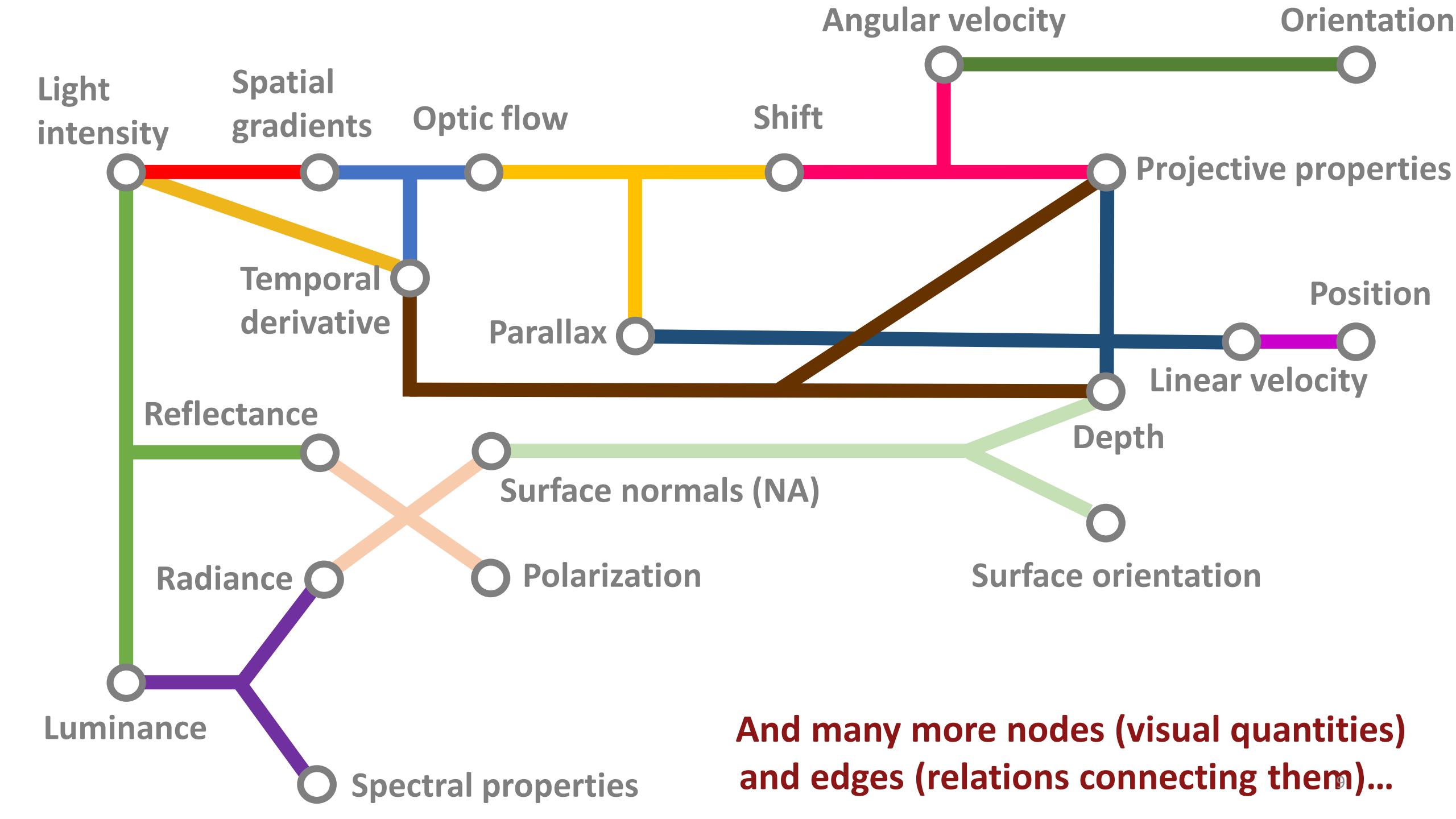




Projective properties

Spectral properties

And many more nodes (visual quantities)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Depth
Surface normals (NA)
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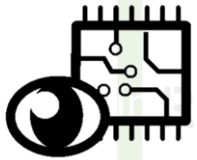
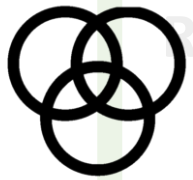
Luminance
Spectral properties
And many more nodes (visual quantities) and edges (relations connecting them)…

1. **Sense** *other* visual *quantities* than direct correlates of “light intensity”

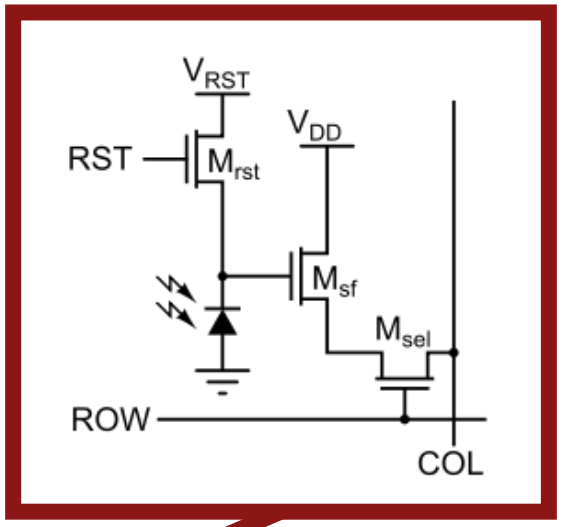


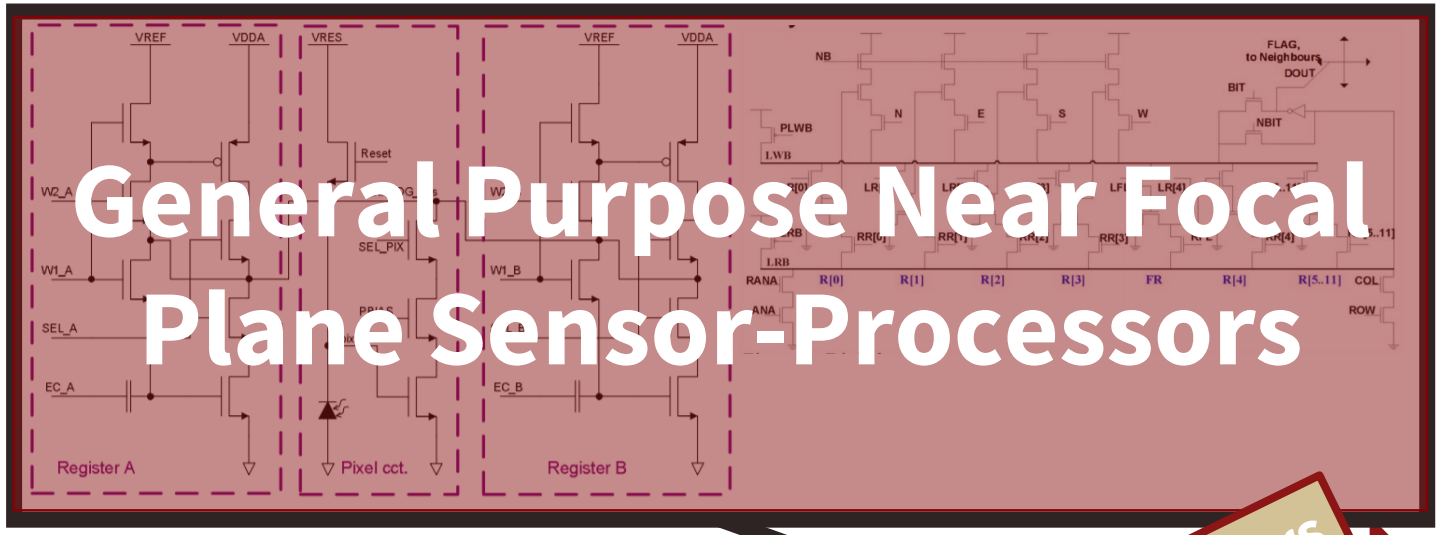
2. **Bring** more *intelligence closer* to the sensor



3. **Design** vision systems *holistically: co-optimizing hardware (optics and sensors) with algorithms*

Bringing more “intelligence” in the pixel



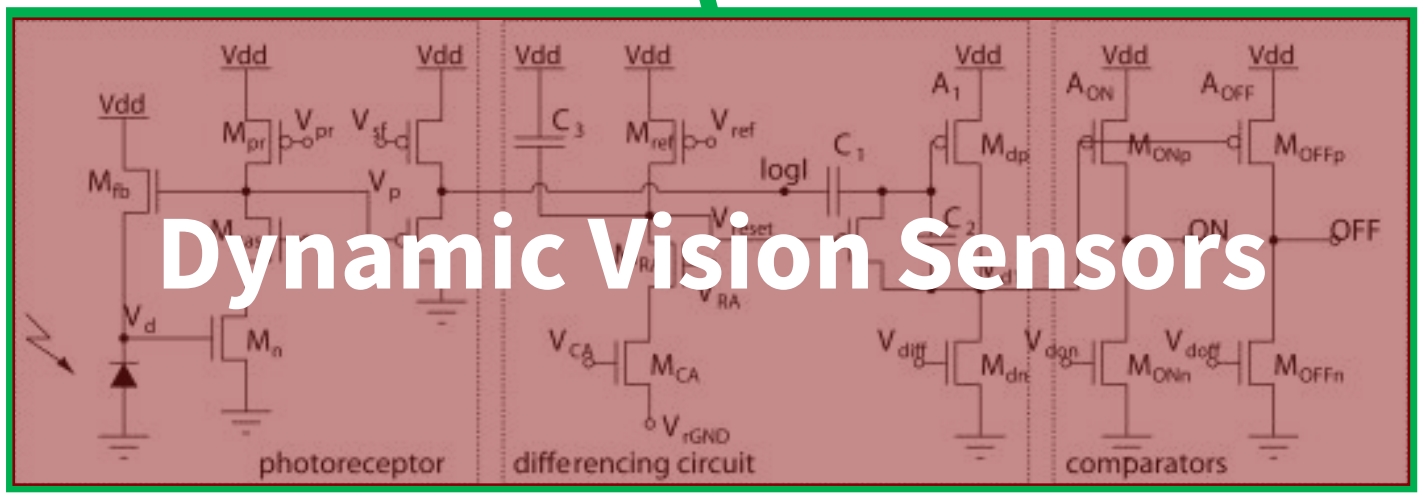


General Purpose Near Focal Plane Sensor-Processors

$\sim 2^1 - 2^2$ $\sim 2^4 - 2^5$ $\sim 2^7 - \cdots$ #transistors

Conventional APS pixel

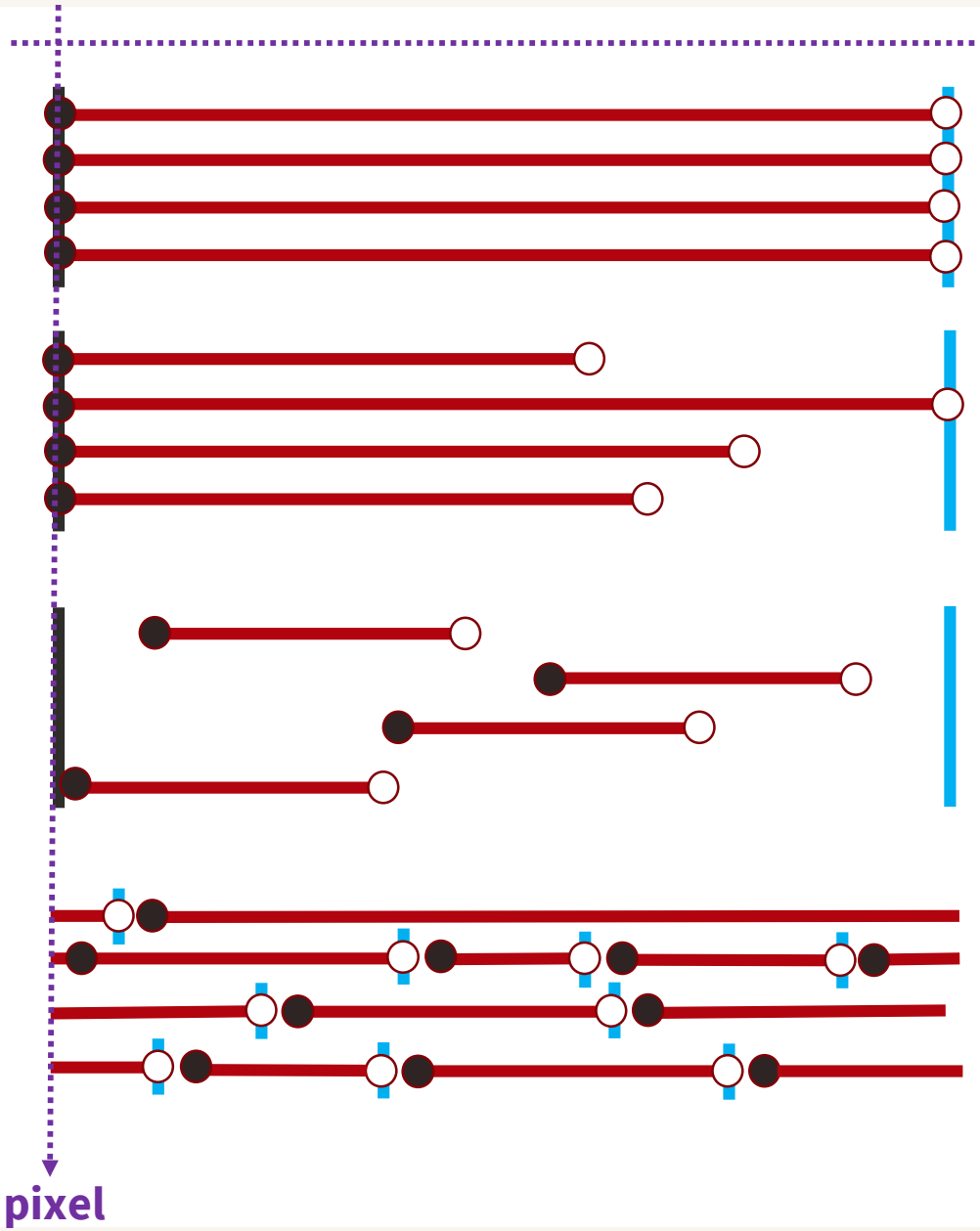
DVS pixel



Dynamic Vision Sensors

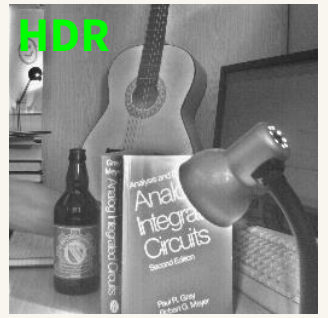
SCAMP-5 pixel (General purpose programmable pixel)

Using pixel “intelligence” to control integration

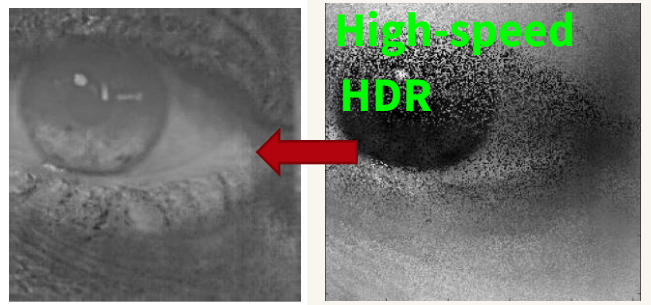


Conventional APS Sensor integration

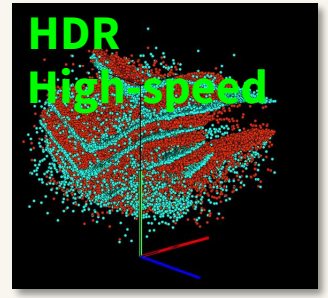
Joint HDR Imaging and Tone Mapping
(Martel, Müller, Carey, Dudek ‘2016)



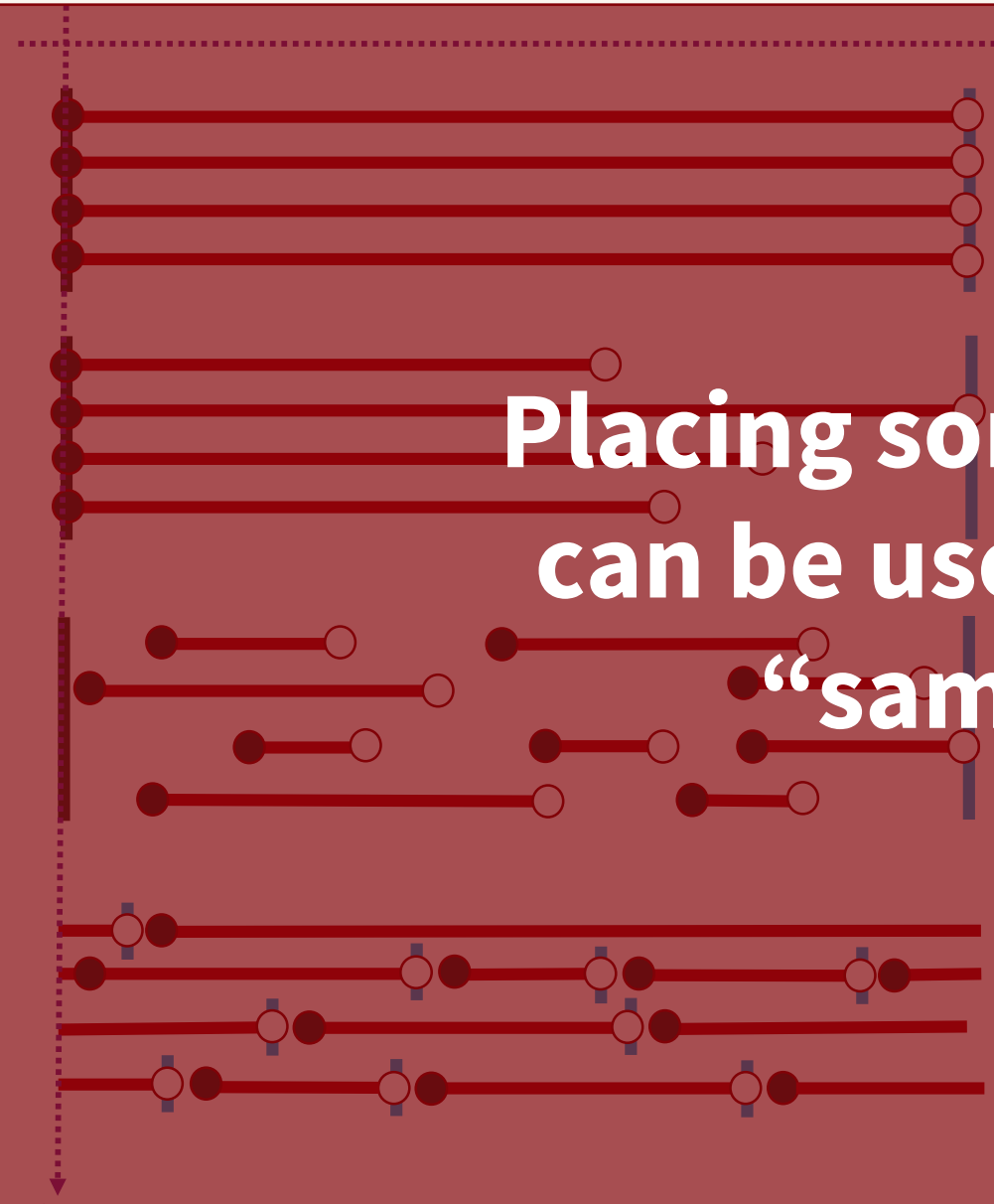
Coded-exposure imaging on the focal plane
(Martel et al. unpublished ‘2019)



Dynamic Vision Sensing



Using pixel “intelligence” to control integration



Conventional APS Sensor integration

HDR

High-speed
HDR

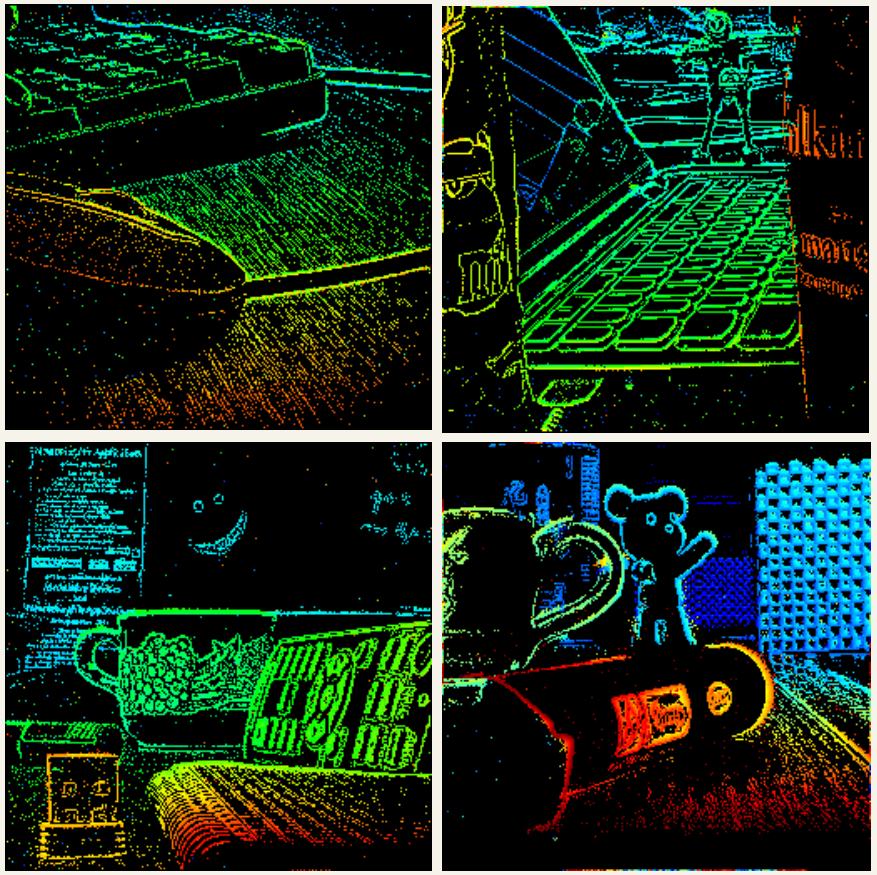
Dynamic Vision Sensing

HDR
High-speed

Placing some intelligence in-pixel can be used beyond adapting its “sampling strategy”…

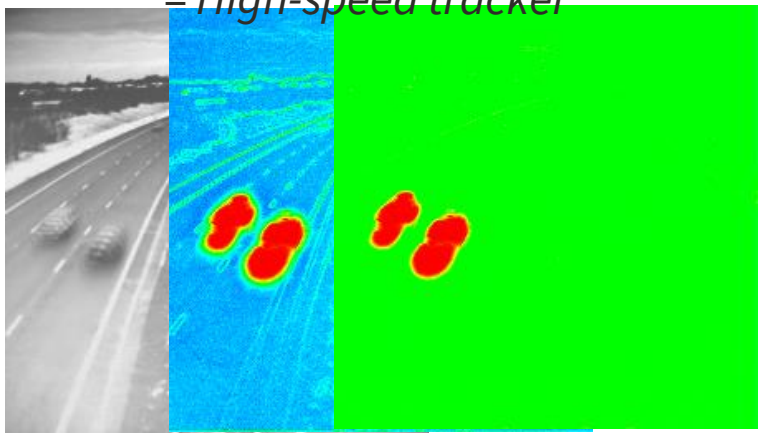
Placing some intelligence in-pixel can be used beyond the control of its integration

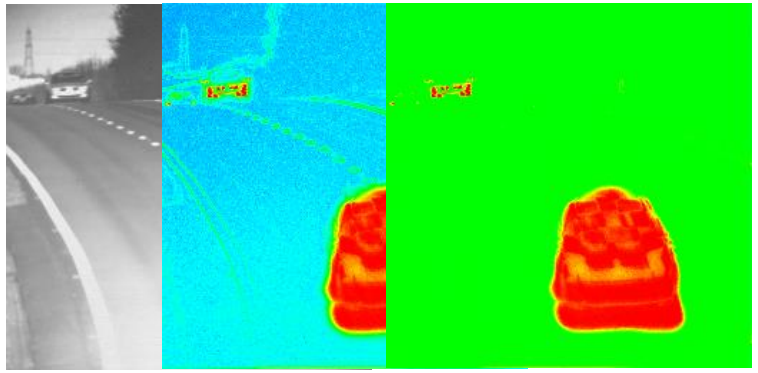
Maximize sharpness on the focal plane
= *High-speed depth from focus*



[Martel et al. ‘17,’18]

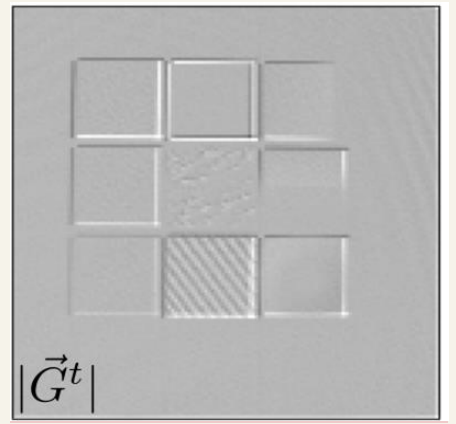
Extract, track and maintain a saliency peak in time on the focal plane
= *High-speed tracker*

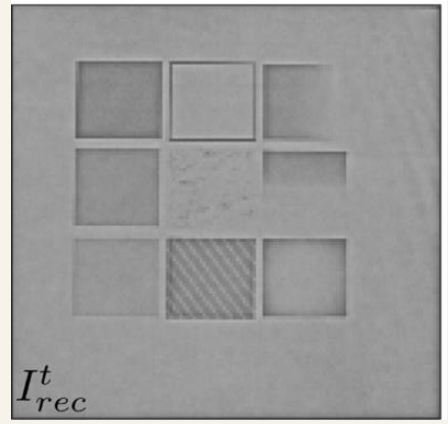




[Martel et al. ’16]

Pixel solving a Poisson equation to reconstruct intensities from a “gradient based imager”

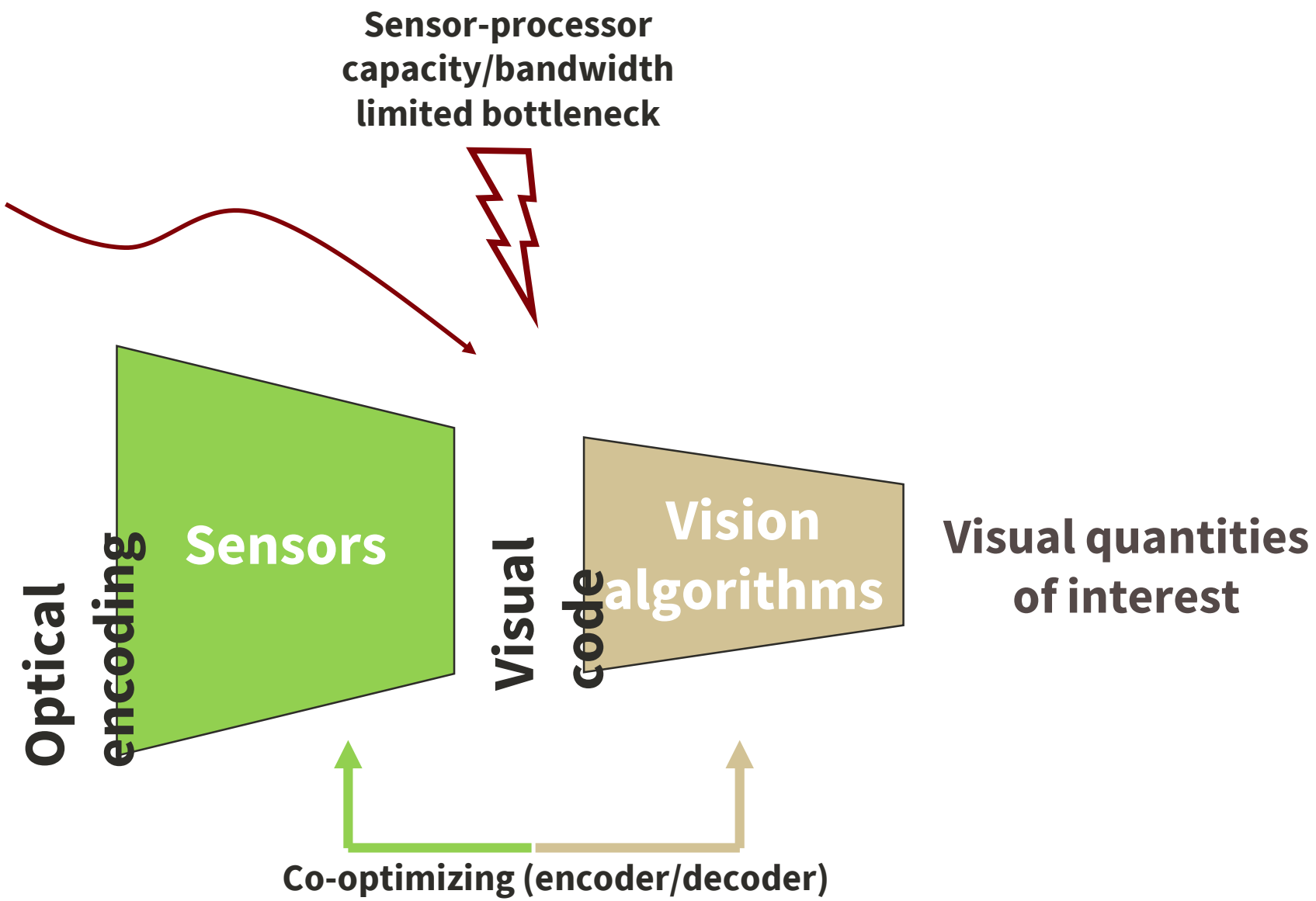




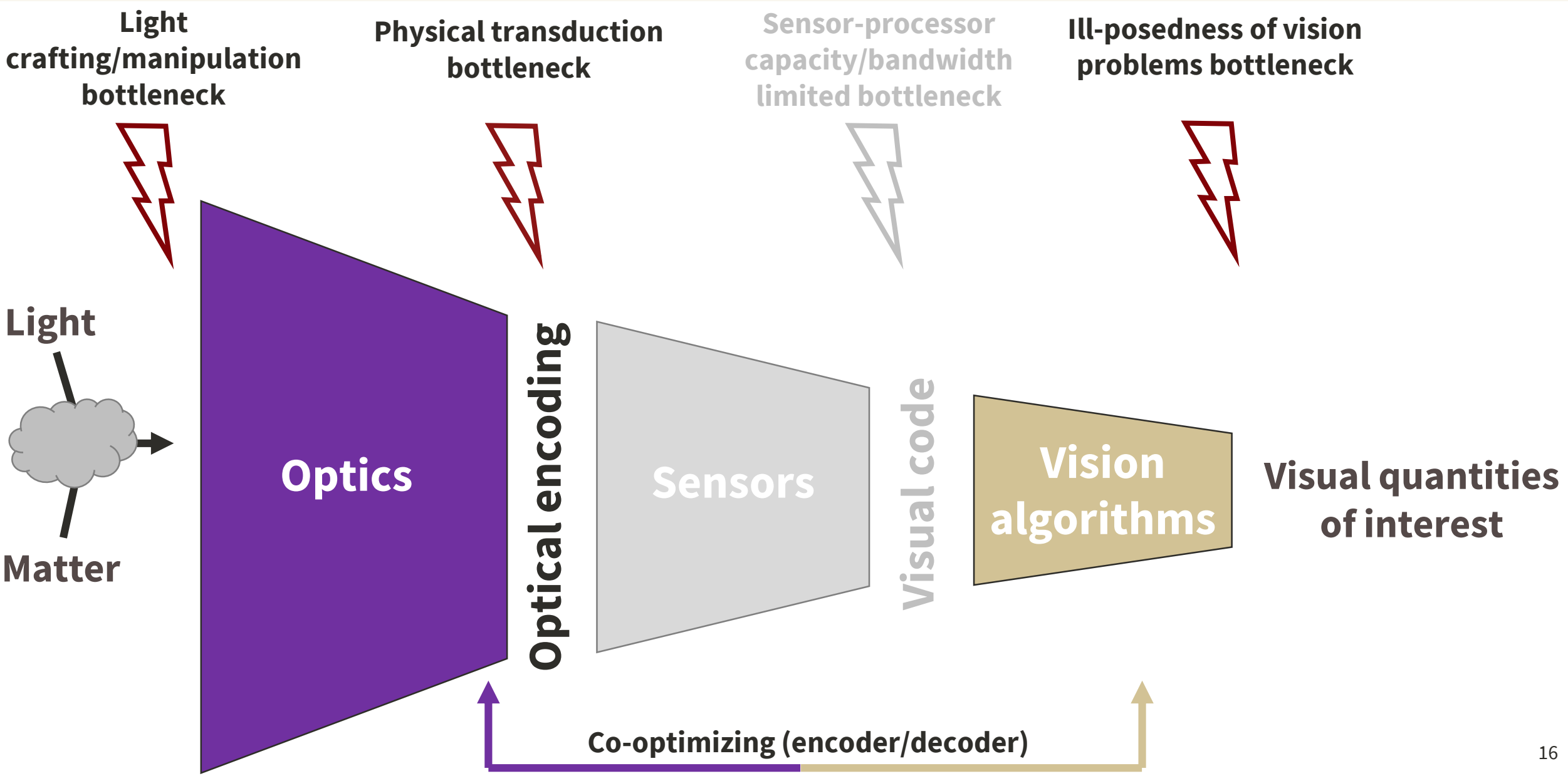
[Martel et al. ’15]

In-pixel “intelligence” mitigates the sensor-processor bottleneck and…

Image,
Coded-image,
Events,
Features,
Timestamps of maximal sharpness,
…

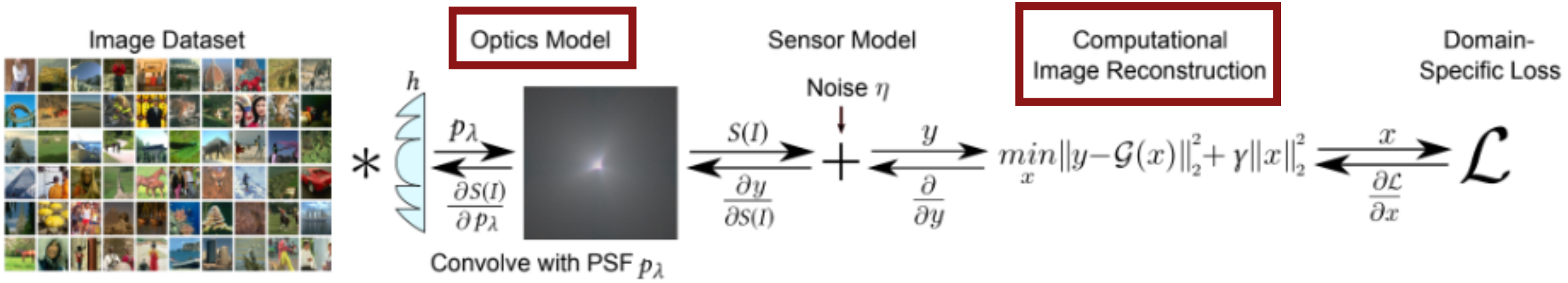


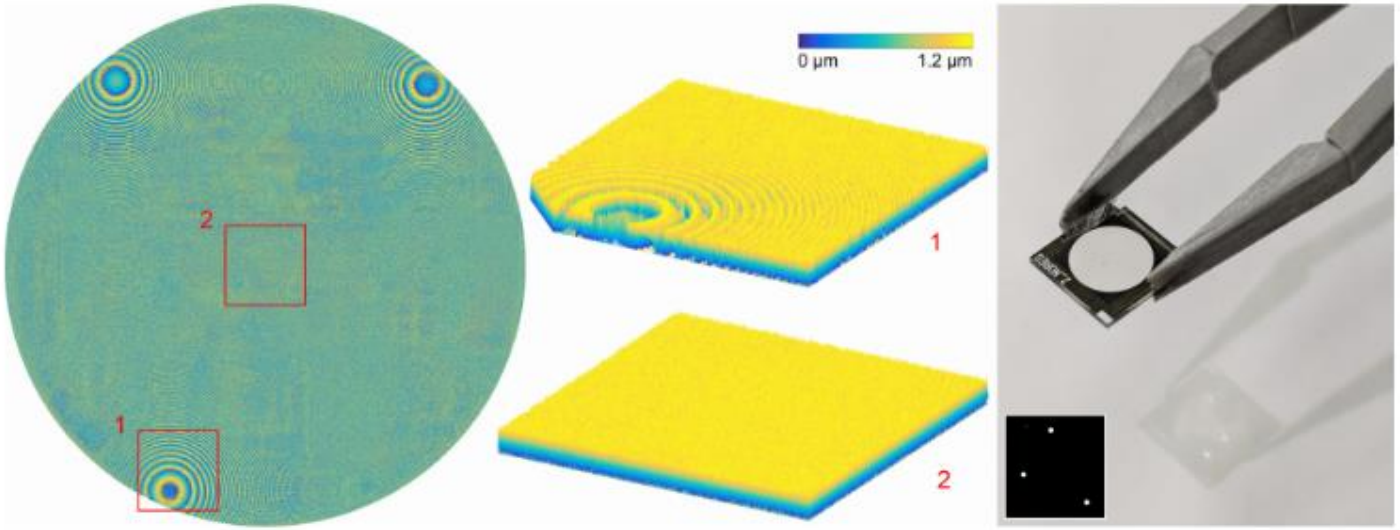
Other bottlenecks addressed by co-optimizing hardware and algorithms



Optimizing optics and vision algorithms altogether…

… for super resolution





End-to-end Optimization of Optics and Image Processing for Achromatic Extended Depth of Field and Super-Resolution Imaging.
(SIGGRAPH'18) V. Sitzmann, S. Diamond, Y. Peng, X. Dun, S. Boyd, W. Heidrich, F. Heide, G. Wetzstein.

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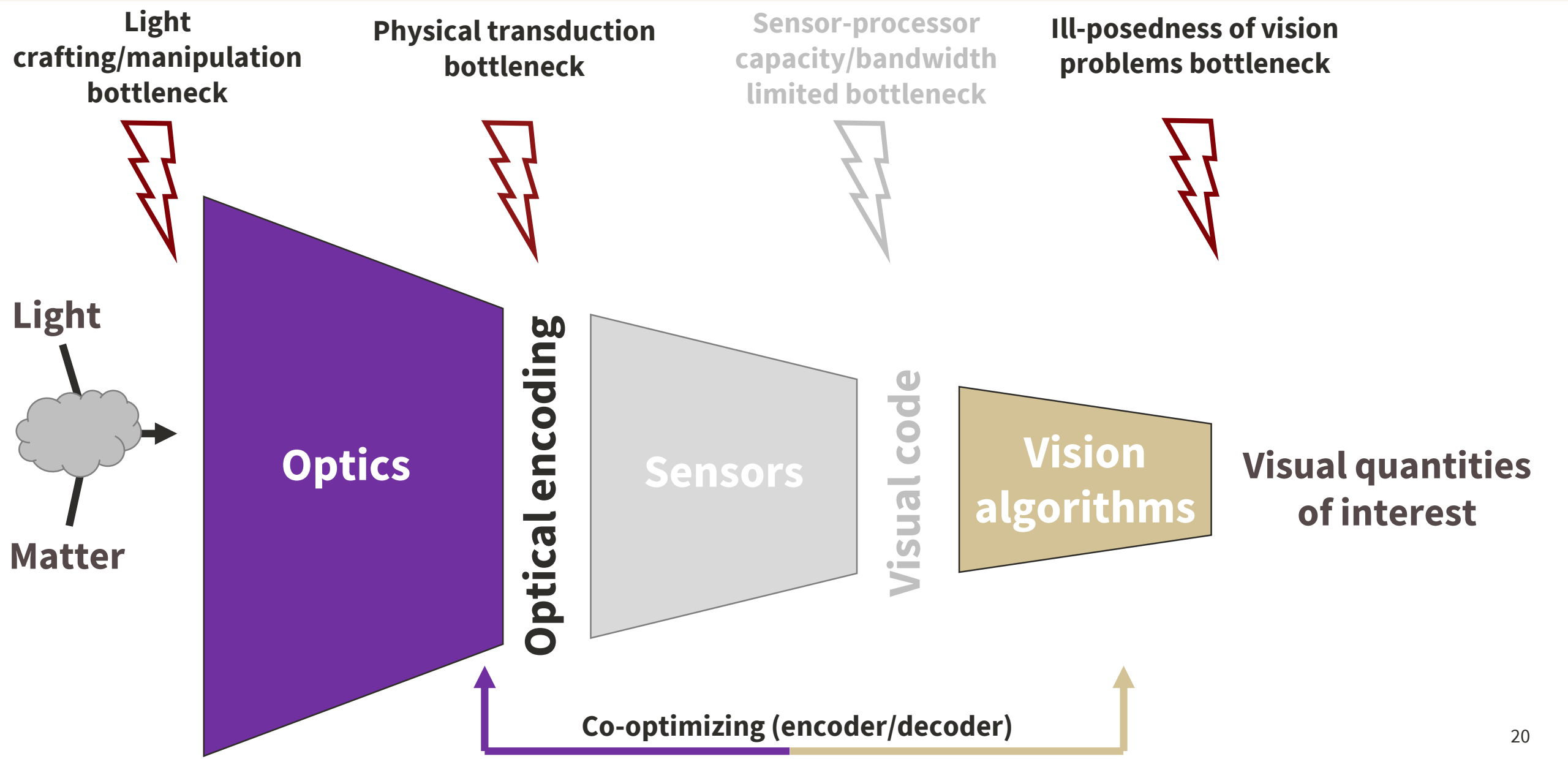
Optimizing optics and vision algorithms altogether…

… for monocular depth imaging

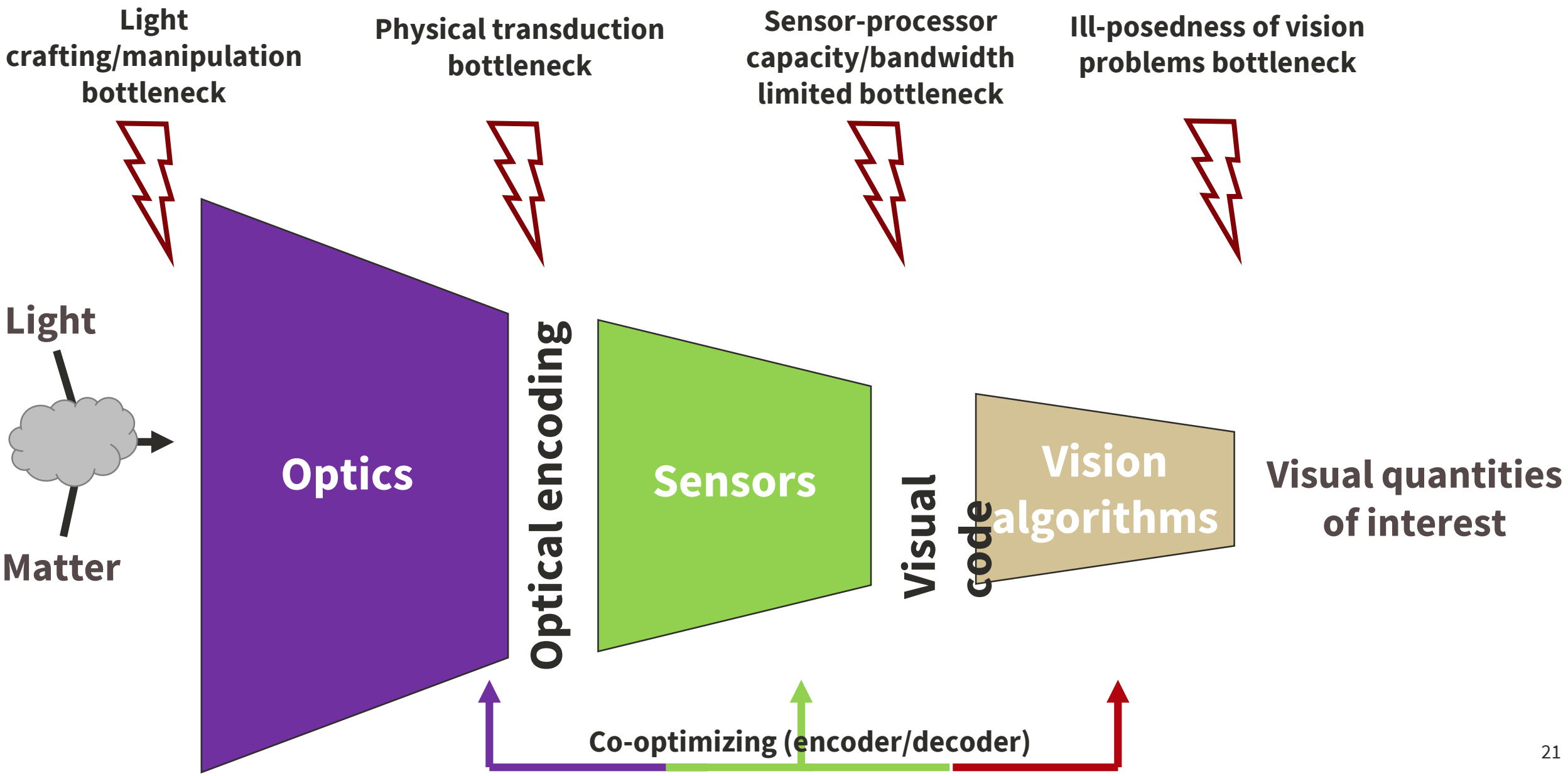
Method	Input	3D object localization			3D object detection		
		Easy	Moderate	Hard	Easy	Moderate	Hard
Mono3D [3]	RGB	5.22	5.19	4.13	2.53	2.31	2.31
MF3D [46]	RGB	22.03	13.63	11.6	10.53	5.69	5.39
MonoGRNet [31]	RGB	-	-	-	13.88	10.19	7.62
VoxelNet [50]	RGB+LIDAR	89.6	84.81	78.57	81.97	65.46	62.85
FPointNet [29]	RGB+LIDAR	88.16	84.02	76.44	83.76	70.92	63.65
(Ours) All-in-focus (val)	RGB	26.71	19.87	19.11	16.86	13.82	13.26
(Ours) Optimized, freeform (val)	RGB	37.51	25.83	21.05	25.20	17.07	13.43

Deep Optics for Monocular Depth Estimation and 3D Object Detection.
(arXiv preprint, 2019) *J. Chang, G. Wetzstein.*

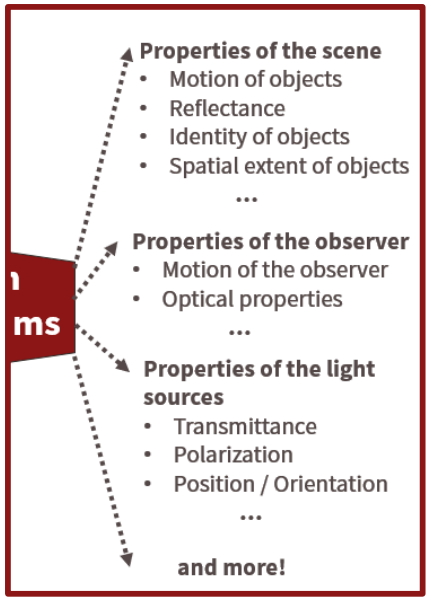
Other bottlenecks addressed by co-optimizing hardware and algorithms



Reconfigurable vision sensors as an opportunity to co-optimize a whole vision pipeline



Wrap up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...
and more!

Acknowledgments

Stanford University

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Daniel **Gehrig,** Davide **Scaramuzza**